Theory Thrust

Developing Theory for Macrocognition Research

Fiore, S. M. & Salas, E. (2007). Developing theory for macrocognition research. *Presentation to the Office of Naval Research Collaboration and Knowledge Interoperability Program,* Arlington, VA, August 9th, 2007.

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Theory Development

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Presentation Overview

- Part I
  - Putting it in *Perspective*
- Part II
  - Pursuing a Multi-level Perspective to Multi-Level Theory Development

Putting it in *Perspective*

Theory Development - *Overarching Objective*

- Can we develop, refine, test, and validate a theory of macrocognition?
  - *Use CKI Program's extant model of collaborative problem solving (Warner et al., 2005) as initial point of departure*
- What constructs and mechanisms contribute to collaboration?
  - *Integrate literatures that both directly and indirectly bear on complex team problem solving activities*

Putting it in *Perspective*

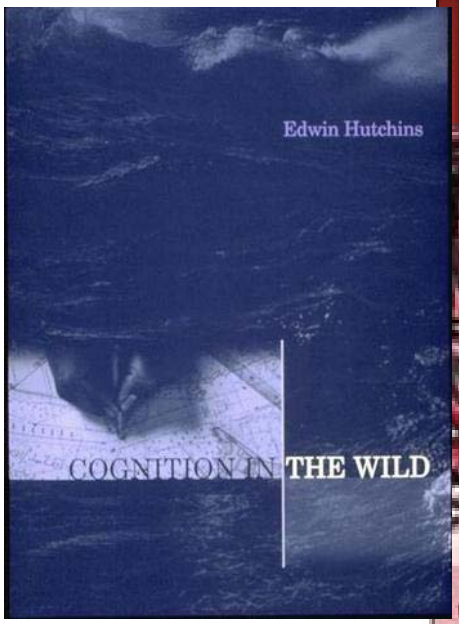
- **Historical Perspective**
  - **An old issue in studies of group performance**
    - Allport, F.H. (1920). The influence of the group upon association and thought. Journal of Experimental Psychology, 3, 159-182.
    - Shaw, M.E. (1932). A comparison of individuals and small groups in the rational solution of complex problems. American Journal of Psychology, 44, 491-504.
    - Thorndike, R.L. (1938). On what type of task will a group do well? Journal of Abnormal Psychology, 33, 408-412.

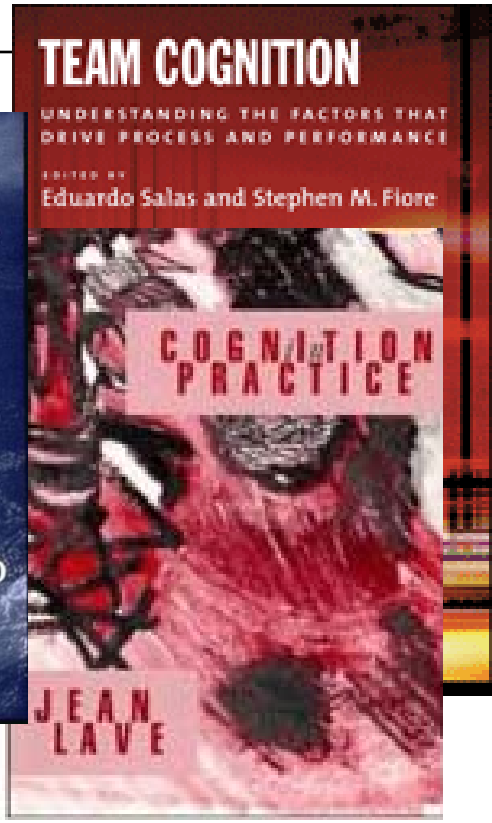
Putting it in *Perspective*

- **Historical Perspective**
  - In early research for the military Glaser (1958) noted:
    - Process variables such as "anticipatory cueing" and "sequence predictability" could facilitate team coordination.
  - Steiner's (1972) seminal work on group productivity noted:
    - Coordination decrements resulted in teams often performing below full potential, a phenomenon he termed *process loss*.
    - *Invariant of difficulty arising when all members attempt to work together at their full potential*

Putting it in *Perspective*

- **Historical Perspectives**
  - **Evolved into:**
    - *Distributed Cognition* in Cognitive Science
    - *Situated Cognition* in Education Research
    - *Team Cognition* in Organizational Research





- **Now Macrocognition**
  - An <u>interdisciplinary integration</u> of varied theories and methods
  - Overarching Epistemological Issue:
    - *How does the manifestation of high level cognition in varied contexts influence collaboration and performance?*

Putting it in *Perspective*

Multidisciplinary research to foster interdisciplinary understanding

- **Multidisciplinary Research**
  - Coordinated efforts of several disciplines to achieve a common goal
  - Contributions from different disciplines are complementary not integrative
  - In service of objective, adopts but not necessarily integrate
- **Interdisciplinary Research**
  - Integration of several disciplines creating a unified outcome
  - Integrates techniques, tools, perspectives, concepts, and/or theories
  - Requires collaboration at the level of designing new types of (experimental) approaches and analysis that combine methods and concepts from different disciplines.
- **Macrocognition represents a focal area to unite different disciplines to solve complex problems – *taking us towards interdisciplinarity***
  - **Research cuts across disciplines:**
    - Psychology, Computer Science, Information Science, Organizational Behavior, Engineering

National Academies, Committee on Facilitating Interdisciplinary Research (2005). *Facilitating interdisciplinary research.* Washington, DC: National Academies Press.

Pursuing a Multi-level Perspective to Multi-Level Theory Development

"Macrocognition at 10^8 Feet" – Perspective at the **Meta-scientific** Level – *Creating Conditions for Collaborative Dialog*

"Macrocognition at 10^5 Feet" – Perspective at the **SUMMIT** Level – *Building Theory for Macrocognition Research*

"Macrocognition at 10^2 Feet" – Perspective at the **Project** Level – *Developing Theoretical Concepts within Macrocognition Research*

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

Creating Conditions for Collaborative Dialog

- Component devoted to developing and sharing the relevance of macrocognition to scientific research for the 21st Century
  - **ASKING: *What do scientists mean by macrocognition?***

- *Developing opportunities for dialog among scientists via symposia at international conferences*
- *Website Development*
- *Special Issue Planning*

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

How have the sciences been using the concept *Macrocognition*?

- *Macrocognition* in ***Neuroscience***
  - Macrocognition refers to "those processes, such as reasoning and communication, where analysis does not take place at the level of the single processing unit" (Bara, 1995, p. 77).

  - Macrocognition is cognition manifest at the cortical network level whereas microcognition is cognition more at neural level (Wilkes, 1997)

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

How have the sciences been using the concept *Macrocognition*?

- *Macrocognition* in ***Cognitive Engineering***
  - "Macrocognition refers to the study of the role of cognition in realistic tasks, that is, in interacting with the environment
  - -- more concerned with human performance under actual working conditions than with controlled experiments" (Cacciabue & Hollnagel, 1995, p. 57).

  - Macrocognition involves contextually bound cognitive processes such as sense making, uncertainty management, in settings such as industrial process control; planning a mission (Hutton, Miller, & Thorsden, 2003; Helander, 2006; Klein et al., 2003).

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

How have the sciences been using the concept *Macrocognition*?

Macrocognition* in *Collaboration and Knowledge Interoperability
(Warner and Letsky, in press)

- Macrocognition is the internalized and externalized high-level mental processes (i.e., combining, visualizing, and aggregating information)
- Resolve ambiguity in support of discovery of new knowledge and relationships
- Employed by teams during complex, one-of-a-kind, problem solving

1. **Have adopted this as SUMMIT projects working definition**
2. **Have been interacting with differing groups on developing shared conceptualization of term**

University of Central Florida
Institute for Simulation & Training
ILLINOIS
University of Illinois at Urbana-Champaign
Arizona State University
University of Pittsburgh

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

Creating Conditions for Collaborative Dialog – *Panel Presented*

- **8th International Conference on Naturalistic Decision Making**

Panel Session
"Multiple Perspectives on the Macrocognition Construct"
8th International Conference on Naturalistic Decision Making

Chairs

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Multiple Perspectives on the Macrocognition Construct (Hoffman & Salas, Chairs)

- **Panel Goals**
  - Advance discussion of differing views of macrocognition
  - Discuss development of measures designed to evaluate macrocognitive team processes
  - Discuss issues arising when developing research environments that support experimentation in macrocognitive processes

- ***SUMMIT beginning a dialogue with NDM community***

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

Creating Conditions for Collaborative Dialog – ***Symposium Presented***

- **Society for Applied Research in Memory and Cognition**

  Macrocognition in Teams: Applying Cognitive Psychology to Support our Understanding of Complex Collaborative Processes (Fiore & Salas, Chairs)

- **Paper Titles**
  - *Understanding Macrocognition in Team Collaboration* - Norman W. Warner and Michael Letsky
  - *Constructing Activity Awareness in Computer Supported Collaborative Work* - John M. Carroll
  - *Cognitively Transforming Individuals into Team Members: Mental Model Convergence and its Impact on Team Performance* - Sara McComb
  - *Linking Ontologies to Support Knowledge Interoperability in Teams* - Webb Stacy
  - *Musings on Macrocognition in Teams and the Application of Cognition to our Understanding of Collaboration* - Stephen M. Fiore and Eduardo Salas
- **Important exposure for SUMMIT and CKI to new community of scholars**

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

Creating Conditions for Collaborative Dialog – *Panel Accepted*

Human Factors and Ergonomic Society – CEDM TG

Macrocognition Metrics: Meaningful Measures for Complex Processes

- Eduardo Salas and Stephen M. Fiore, Panel Chairs

Paper Titles

- ***Macrocognition in Collaboration and Knowledge Interoperability***
  - Michael Letsky, Office of Naval Research
- ***Macrocognition and Complex Cognitive Systems***
  - Gary Klein, Applied Research Associates and Robert Hoffman, Institute for Human and Machine Cognition
- ***Communication-Based Metrics of Macrocognition***
  - Nancy J. Cooke, Arizona State University
- ***Triangulating Metrics for Assessing Macro-Level Cognitive States: Pushing the Way Forward***
  - C. Shawn Burke, University of Central Florida
- ***Metric of Rigor in Distributed Analysis***
  - Emily S. Patterson, Ohio State University

Human Factors and Ergonomics Society

SUMMIT promoting dialogue on macrocognition

"Macrocognition at 10^8 Feet"
– *Perspective at the Meta-scientific Level*

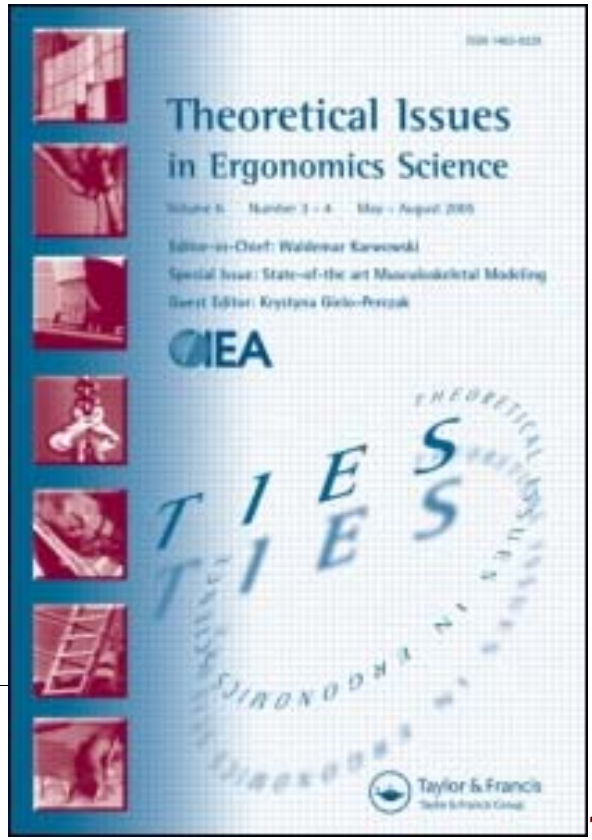
Creating Conditions for Collaborative Dialog

- **Website Development Update**
  - *Expanded Definitions*
  - *Password Access to DRAFTS*

Creating Conditions for Collaborative Dialog

Developing Invited Special Issue for the journal *Theoretical Issues in Ergonomic Science*

- Topic related to Macrocognition
  - *Collaboration and Cognition in Context*
    - Will invite theoreticians from differing disciplines to contribute
    - Discuss theoretical issues surrounding:
      - *Interplay between intra- and inter-individual cognition*
      - *Influence of contextual variations*



"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Bounding Theoretical Issues

- This component is addressing need to identify boundary conditions around theorizing related to macrocognition.
  - **ASKING: *How will SUMMIT explore macrocognition?***

- *SUMMIT Working Papers identifying and articulating theoretical issues related to Macrocognition*
  - *White Paper 1.1. Memorandum of Understanding – Theory Development on Macrocognition in Teams.*
  - *White Paper 1.2. Micro- Meso- and Macro-levels of Analysis in Collaborative Problem Solving.*
  - *White Paper 1.3. Diagnosing Macrocognition in Teams "In the Head" and "In the World".*

"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Bounding Theoretical Issues

White Paper 1.1. Memorandum of Understanding – Theory Development on Macrocognition in Teams

- Worked with CKI Program towards common ground on theory development
  - Goal to ensure outlining conditions appropriate for explanatory model
    - Ensure boundary conditions are identified
  - Articulate what is meant by initial parameters used to create model
    - Homogeneity/heterogeneity within teams - Talking about national cultures (e.g., NATO) or talking about military cultures (i.e., joint forces), or both?

- Types of teams for model
  - Talking about multi-team systems, or distributed-intact teams or teams of teams
- Nature of the task environment
  - Task structure
  - Task complexity

"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Bounding Theoretical Issues

White Paper 1.2. Micro- Meso- and Macro-levels of Analysis in Collaborative Problem Solving.

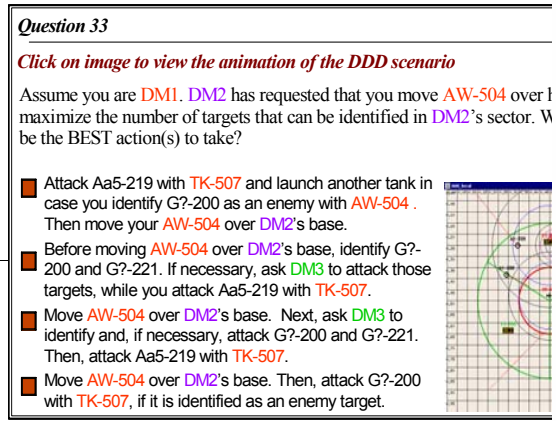
- **Macrocognition as Complex System -** *Consists of web of frequently non-linear interrelations between variables*
  - Large number of components, self-organization, and emergence.
  - Address multi-level and multi-causal phenomena of open systems
- Not ignore interactions among multiple levels
  - *Multi-level theory to create cross-level models - variables impact relationship of upper-level and/or lower-level variables (Klein, Tosi, & Cannella, 1999)*
- May improve diagnosis of causal factors
  - *Hackman (2003) demonstrated that moving up or down level of analysis adds explanatory power*

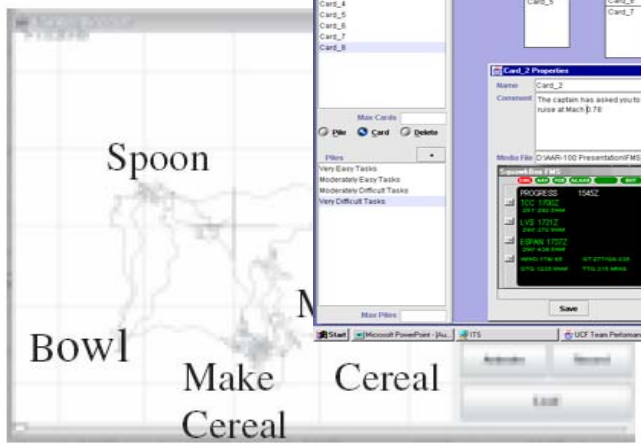
"Macrocognition at 10^5 Feet"
– Perspective at the SUMMIT Level

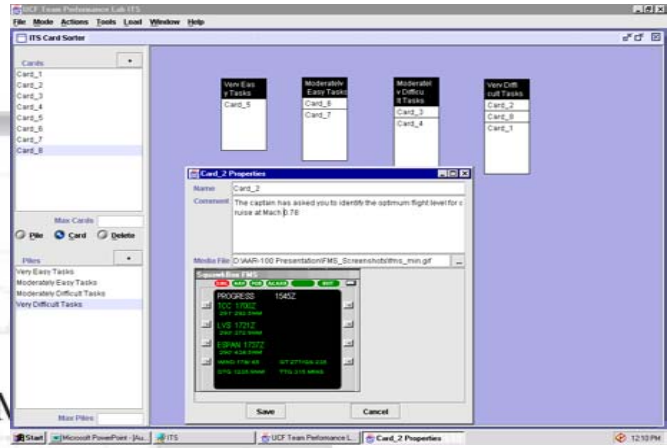
Developing Theoretical Concepts

White Paper 1.3. Diagnosing Macrocognition in Teams "In the Head" and "In the World"

- Theoretical issue of where macrocognition resides
  - *In minds of individual team members, as an emergent property visible via the interactions of the teams, or some combination of the two*
- Adopting cognitive science concepts at individual level for consideration of measuring at macrocognition level
  - Off-line measures - knowledge related to problem solving
    - Sensitivity and Bias – to conceptual relations
    - Simulation Vignettes – knowledge integration
  - On-line measure of process/movement
    - Process Flow – tracking measures







"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Building Theory

- This component is addressing need to evolve theorizing related to macrocognition.
  - **ASKING: *What does SUMMIT mean by macrocognition?***

Developing papers to identify and articulate theoretical issues related to Macrocognition

Fiore, S. M., Rosen, M., Salas, E., Burke, S., & Jentsch, F. Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space. To appear in M. Letsky,, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams.* London: Ashgate.

Letsky, M., Warner, N., Fiore, S.M., Rosen, M.A., & Salas, E. (2007). Macrocognition in Complex Team Problem Solving. *Proceedings of the 12th International Command and Control Research and Technology Symposium*. Newport, RI.

- ***Initial Definitions of Terms***
- ***Matrix of Functions, Processes, and Stages***

Letsky, M., Warner, N., Fiore, S.M., Rosen, M.A., & Salas, E. (2007). Macrocognition in Complex Team Problem Solving. *Proceedings of the 12th International Command and Control Research and Technology Symposium*. Newport, RI.

Functions and Processes	Collaboration Stages			
	Knowledge Construction	Problem Solving	Consensus	Evaluation and Revision
Individual/Team Knowledge Building and Development				
Pattern recognition				
Mental model development				
Recognition of expertise				
Sharing unique knowledge				
Uncertainty reduction				
Problem Conceptualization				
Visualization of data, meaning				
Building common ground				
Knowledge sharing and transfer				
Team problem model				
Shared understanding development				
Manipulating Problem Conceptualization				
Critical thinking				
Mental simulation				
Intuitive Decision Making				
Option generation				
Storyboarding				
Consensus Development				
Negotiation				
Outcome Appraisal				
Feedback structure				
Replanning				
Stage Invariant Processes				
Coordination				
Team learning				
Workspace awareness				

"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Building Theory

Fiore, S. M., Rosen, M., Salas, E., Burke, S., & Jentsch, F. (in press). Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space. To appear in M. Letsky,, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams.* London: Ashgate.

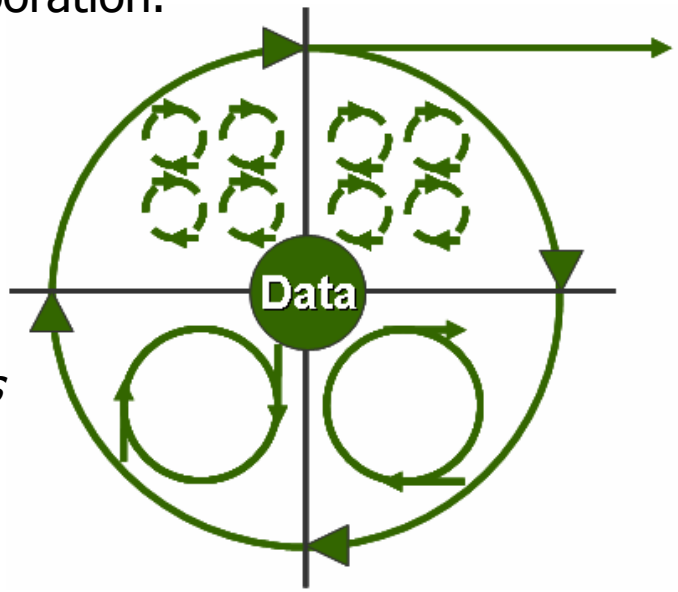
- Evolving conceptualization of CKI macrocognition theory
  - Next step of definitional exercise (Letsky, Warner, Fiore, Rosen, & Salas, 2007)
  - Attempt to reify concepts within context of what Letksy et al. (2007) have described as internalized and externalized cognition.
  - More clearly convey the inter-relations among macrocognitive processes

"Macrocognition at 10^5 Feet" – *Perspective at the SUMMIT Level*

Building Theory

Fiore, S. M., Rosen, M., Salas, E., Burke, S., & Jentsch, F. (in press). Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space. To appear in M. Letsky,, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams.* London: Ashgate.

- Figure illustrates conceptual representation - Parallel, interdependent, and iterative nature of processes unfolding in the context of collaboration.
  - Illustrates two, four person teams interacting to solve a problem.
    - Arrows represent iterative nature of these processes as unfold individually and collectively.
    - *Illustrates overall iterative nature of process as it unfolds over individuals, teams, and across teams.*

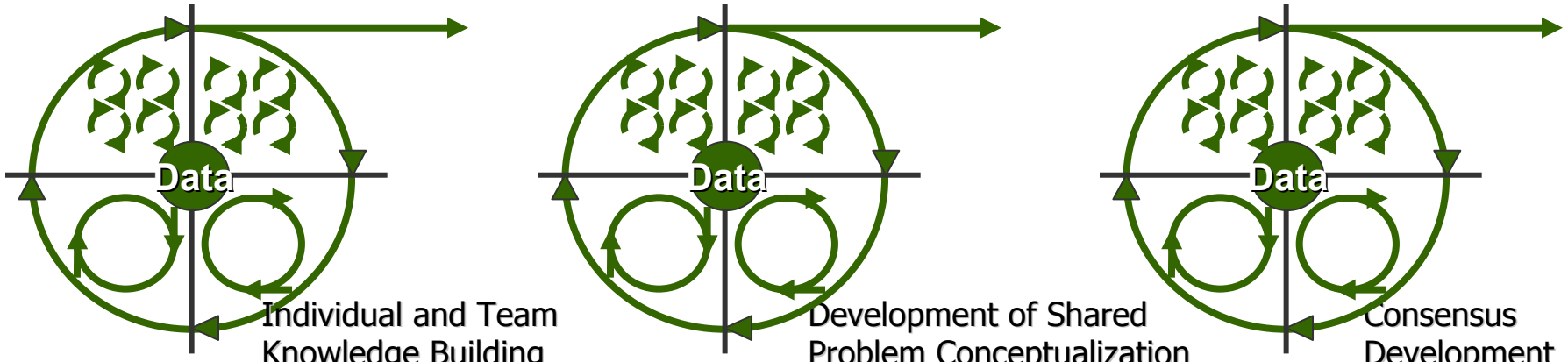


"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Building Theory - Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space

Thematic Elements

- Can evaluate what is occurring as collaboration unfolds
  - See that as teams move through stages of problem solving, there is a continual process of an "effort after meaning" (cf. Bartlett, 1932)
- We see an evolution of understanding within the team based upon:
  - Interplay between the perceptual *and* conceptual - integrating visual and verbal understanding to make meaning
  - Increases in complexity
    - Evolving from pattern recognition to visualization of data meaning to storyboarding

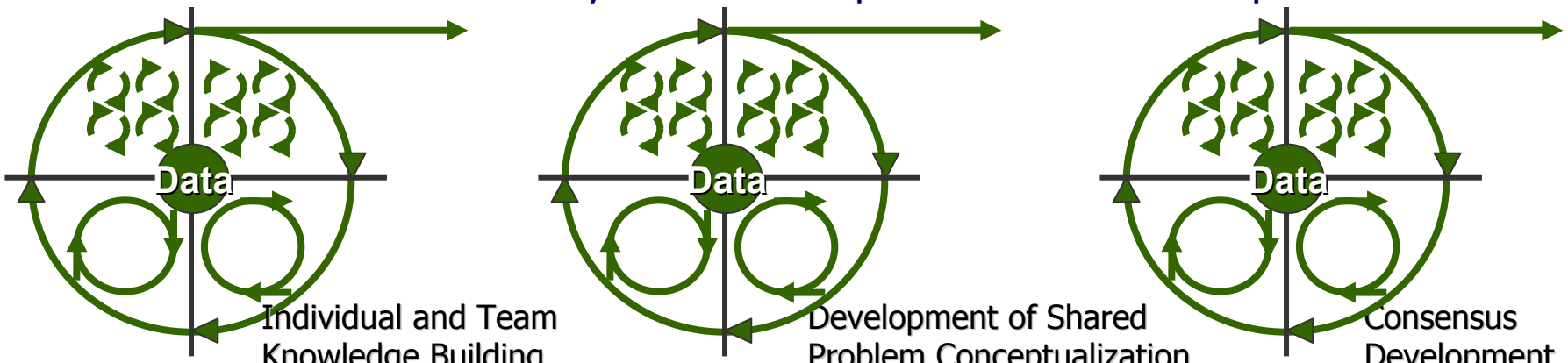


"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Building Theory - Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space

Thematic Elements

- Continual interplay between internalization and externalization
  - For example, pattern recognition and mental model development along with sharing unique knowledge and recognizing expertise
- Understanding of constituent elements is acquired and then integrated for higher level interpretation and sharing
  - At core of collaborative problem solving
    - Interpreting and Interacting – Process information arising from the environment and held by team to comprehend elements of problem situation

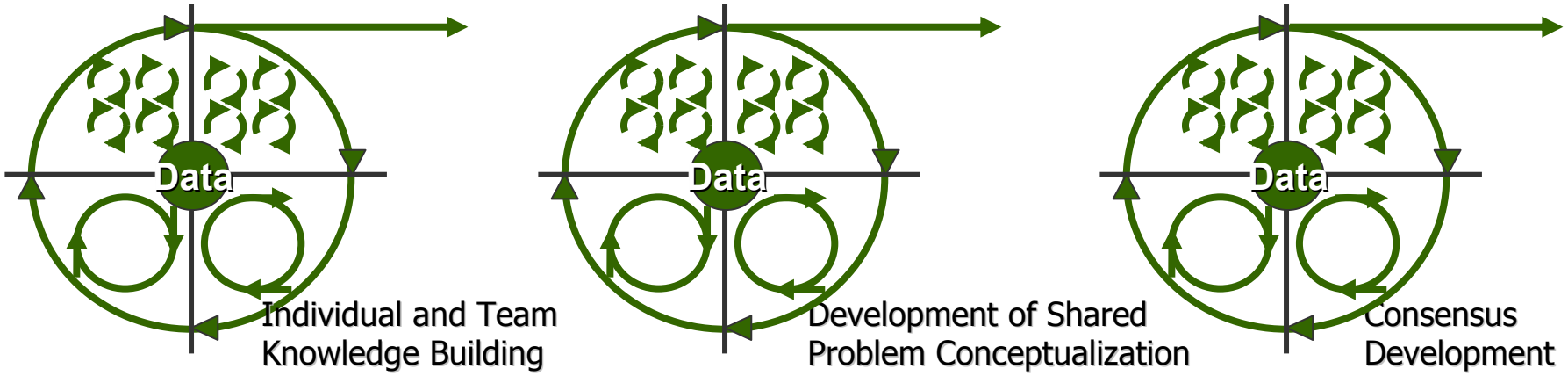


"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

Building Theory - Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space

Thematic Elements

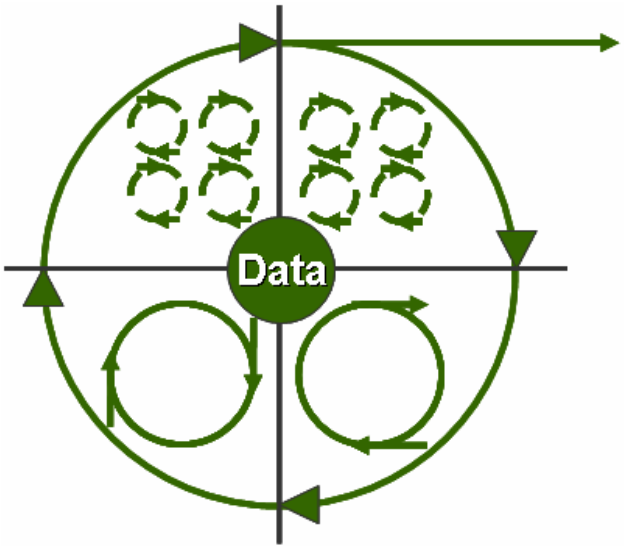
- Evolves from reduction of uncertainty early in the process as team considers both data and their teammates to determination of plausibility
  - Initially, teams interact with environment and each other to better understand information arising from each
  - Processes are then engaged to act upon acquired knowledge and evaluate utility and realizability of course of action



"Macrocognition at 10^5 Feet"
– *Perspective at the SUMMIT Level*

From This - Theoretical Drivers for our Research

- Driver 1. Examine the evolution of understanding within the team:
  - Examine the interplay between the perceptual *and* conceptual in collaborative problem solving
- Driver 2. Understanding iterative nature of internalization *and* externalization of knowledge
  - Assess how *interpretation* and *interaction* within teams support comprehending task elements
- Driver 3. Understanding evolution from uncertainty reduction *to* determination of plausibility
  - Explore macrocognitive processes driving information interrogation and evaluation during collaboration



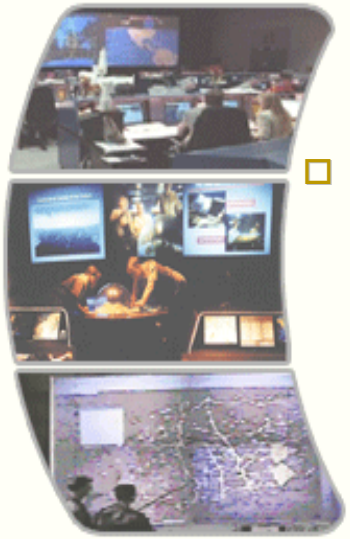
"Macrocognition at 10^2 Feet"
– *Perspective at the Project Level*

Developing Theoretical Concepts for Experimentation

- This component is developing and augmenting existing concepts for macrocognition research
  - **ASKING:** ***How can we enrich understanding of foundational macrocognition concepts through empirical studies?***

- **Concepts for Macrocognition Experiments**
  - General Theoretical Issues
    - *Understanding Problem Space and Impact of Task*
- Will present in discussion of Experiment Thrust

Next Steps for Multi-level Perspective to Multi-Level Theory Development



- "Macrocognition at 10^8 Feet" – Perspective at the **Meta-scientific** Level
  - Creating Conditions for Collaborative Dialog - *NEXT STEPS:*
    - *Prospectus for special issue and continued conference participation*
- "Macrocognition at 10^5 Feet" – Perspective at the **SUMMIT** Level
  - Building Theory for Macrocognition Research - *NEXT STEPS:*
    - *Finalize chapter describing theory*
    - *Prepare next iteration of theory development*
      - *Manuscript with research propositions*
      - *Manuscript integrating metrics*
- "Macrocognition at 10^2 Feet" – Perspective at the **Project** Level
  - Developing Theoretical Concepts within Macrocognition Research - *NEXT STEPS:*
    - *Pursue experimentation based upon initial theorizing*

Macrocognition at Multiple Levels - *Theory Thrust Year One Papers and Presentations*

Panels/Symposia

Fiore, S.M. & Salas, E. (2007). Macrocognition in Teams: Applying Cognitive Psychology to Support our Understanding of Complex Collaborative Processes. Panel presented at the *7th Biennial Meeting of the Society for Applied Research in Memory and Cognition.*

Salas, E., & Fiore, S.M. (2007). Macrocognition Metrics: Meaningful Measures for Complex Processes. Panel to be presented at the *50th Annual Meeting of the Human Factors and Ergonomic Society.*

Salas, E., & Hoffman, R. R., & Fiore, S.M. (2007). Multiple Perspectives on the Macrocognition Construct. Panel presented at the *8th International Conference on Naturalistic Decision Making.*

Chapters/Articles Year One

Fiore, S. M., Rosen, M., Salas, E., Burke, S., & Jentsch, F. (in development). Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space. To appear in M. Letsky,, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams*. London: Ashgate.

Rosen, M.A., Salas, E., Fiore, S.M., Letsky, M., & Warner, N. (under review). Tightly Coupling Cognition: Understanding how Communication and Awareness Drive Coordination in Teams. *International Journal of Command and Control.*

Presentations Year One

Rosen, M. A., Feldman, M., Fiore, S. M., & Salas, E. (under review). Augmented Team Cognition for Complex Problem Solving Tasks. Preliminarily accepted to *Augmented Cognition International.*

Rosen, M. A., Lazarra, E.H., Fiore, S.M., & Salas, E. (2007). Team problem solving tasks: A conceptual review and integration. *Second Annual Interdisciplinary Network for Group Research Conference*, Lansing, MI.

Sims, D., Rosen, M. A., Fiore, S. M., & Salas, E. (2007). Macrocognition: How dense are our teams? *Second Annual Interdisciplinary Network for Group Research Conference,* Lansing, MI.

SUMMIT Working Papers

- *White Paper 1.1. Memorandum of Understanding – Theory Development on Macrocognition in Teams.*
- *White Paper 1.2. Micro- Meso- and Macro-levels of Analysis in Collaborative Problem Solving.*
- *White Paper 1.3. Diagnosing Macrocognition in Teams "In the Head" and "In the World".*
- *White Paper 1.4. Theoretical Multilevel Issues for Measuring Complex Team Performance*

Thank You

Questions or Comments?